Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them	)))))	PR Docket No. 92-235

REPLY COMMENTS OF UNITED PARCEL SERVICE

United Parcel Service of America (UPS) hereby submits its reply to comments submitted in this proceeding. UPS welcomes the FCC's "refarming" *Notice of Proposed Rule Making* (NPRM), as an initiative with great potential to improve the availability and performance of private land mobile radio (PLMR) communications for decades to come.

UPS's extensive use of mobile RF communications in its operations motivates its interest in these proceedings. For the same reason, it participated extensively in the 220-222 MHz proceedings. UPS's II Morrow, Inc., subsidiary has developed type accepted narrowband digital FM radios and system technology for the 220-222 MHz band.

UPS's experience with 150 MHz in major markets acquainted it with the practical realities of introducing narrowband technology into crowded land mobile bands. UPS succeeded in establishing 150 MHz narrowband data systems in a number of US cities. Several are still in use, supporting UPS On Call Air service. Others proved unsatisfactory because of adjacent channel considerations.[1] While systems operating at 220 MHz will eventually support much of UPS's communications needs, UPS also looks forward to the development of more efficient systems in other PLMR bands.

In various important respects, the NPRM builds on the 220-222 MHz rulemaking, and promotes positive standards for the evolution of the PLMR Service. The NPRM stimulated a large and diverse body of comments. On review of the comments, UPS believes it is important to reiterate and reinforce the input it provided in the May 6, 1993, FCC Roundtable on Refarming and to provide its perspective on the use of channels as narrow as 5 kHz in light of questions raised in comments concerning the desirability of channels this narrow. UPS's experience in the 220-222 MHz band, work with narrowband radio at 150 MHz, and use of wider band RF systems operating in the 450-470 and 800 MHz bands, both voice and data, provide the background for these replies.

The appendices to these Reply Comments address a series of topics related to refarming: 5 kHz, 6.25 kHz, and 12.5 kHz single channel systems; TDMA; spread spectrum; wideband data; and mixed voice-data systems. UPS considers various aspects of each topic: spectrum efficiency; operational features and characteristics; relative cost; and availability. UPS also includes examples of analysis of spectrum efficiency for actual applications, emphasizing the tremendous gains in useful channel capacity attainable with digital techniques.

Three major themes manifest themselves within the Technical Appendices attached

[1] A tighter emission mask makes 220 MHz equipment much more effective from the standpoint of operating in an adjacent channel environment than the current 150 MHz narrowband equipment.

hereto:[2]

(1) The emission masks in the NPRM, plus provisions for flexible use of contiguous channel blocks, offer a viable blueprint for compatibility among a number of different cost effective, spectrum efficient technologies. The NPRM masks are based on the 220 MHz mask, which allows a wide variety of modulations without requiring adjacent channel coordination.

(2) A wide range of different technologies can be successfully implemented for the use of channels as narrow as 5 kHz. Three different companies have received 220 MHz type acceptance grants to date, using three different modulations. Two use linear transmitters: amplitude compandored single sideband (ACSSB) and transparent tone in band (TTIB).[3] The other type accepted 220 MHz modulation is narrowband digital FM, using nonlinear transmitters.

(3) Type accepted, field tested 220 MHz FM digital radios and packet data system technology developed by UPS's II Morrow subsidiary have already demonstrated tremendous practical gains in spectrum efficiency. UPS's 220 MHz technology has two major aspects: (i) narrowband digital FM radios; and (ii) software for highly efficient channel access, cell roaming, and local or wide area networking. The radios and system software work in close concert, using important advantages of digital FM to allow hundreds of mobiles to operate on each individual 5 kHz channel, making thousands of reliable message transfers per hour. In addition to field tested data performance, lab tests show that the narrowband FM radios also have the basic capabilities to support digital voice.

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[2] [illegible]

Refarming transition timing and allowed efffective radiated power and height above select those approaches to refarming that best serve the overall public interest. In particular, the presence of existing users and the need to transition without undue economic hardship will naturally need to be weighed carefully in the public interest balance as the Commission reaches decisions on refarming. Nevertheless, the 220 MHz proceedings and the technological advances flowing from the effort to make efficient use of that band have already yielded very useful insights that should be considered in the refarming effort.

Conclusion

In the congested PLMR bands below 512 MHz, the transition to channels as narrow as 5 kHz is both feasible and generally desirable. Users will be able to employ a choice of modulations that can meet a wide variety of needs in a cost effective manner. Technology has already been developed and proven that makes feasible high capacity narrowband (5 kHz channels) mobile data radio networks at 220 MHz. There is every reason to expect that progress will continue with the end result being a more efficient PLMR Service that better supports the

Appendix 1

Analysis of Technical Options for Greater Spectrum Efficiency in the Private Land Mobile Radio Service

I. Background

II Morrow is a wholly owned subsidiary of UPS, acquired to provide UPS with technologies required to maintain its position as the worldwide leader in package distribution services. Since 1987, II Morrow has furnished vehicle tracking, in-vehicle monitoring, and mobile communications technologies and products for UPS. II Morrow's prior experience in vehicle tracking systems for applications such as construction, forestry, and public safety was a major factor in the UPS acquisition.

UPS and II Morrow actively supported and participated in the FCC's 220-222 MHz proceedings. UPS participated not as an equipment or system vendor, but because mobile RF communications are greatly needed to meet significant operational requirements of many businesses, including its own. Increasingly over the last several years, channel congestion and spectrum crowding have become a serious fact of life in the VHF and UHF PLMR bands.

UPS is continually expanding customer services such as package tracking, on call pickup, and expedited delivery. UPS's customers demand current information on package location, expected delivery times, and delivery confirmation. Providing these services requires extensive communications and data processing.

As an example, UPS's on call pickup service uses vehicle location to determine assignments. When a customer requests a pickup, a dispatch computer determines which vehicle can make the pickup with the least delay and minimum schedule changes. This decision is based on current vehicle positions, determined by Loran or GPS position sensors, direction of movement, and ease of access to the pickup location. The mobile radio system communicates position updates, stop completion reports, and new assignments between the vehicles and the dispatch center.

To improve customer service and reduce costs, UPS plans to consolidate on call dispatching into regional centers. The ability to provide real-time vehicle location to a regional dispatcher allows cost effective pickup assignment decisions. In conjunction with map data base software, this enhances on call pickup service, even when the regional dispatcher does not have first hand knowledge of local one way streets, divided highways, ramp locations, bridges, or ongoing construction. Regional dispatching requires connectivity between the mobile radio system and UPS's nationwide data network.

UPS also plans to enhance the efficient use of its vehicle fleet by providing feeder tractor advanced hub arrival notification, on-property digital two-way communications for hub yard management, and automatic trailer bay identification. These operational capabilities will minimize energy costs, operating and maintenance expenses, and environmental impacts. Meeting these service and operational objectives requires some form of mobile communications capability in each UPS vehicle.

Once the parameters of this proposed vehicle communications system were identified, II Morrow began working to make the plan a reality. Numerous options were considered, including leasing channel space from both common carriers and private entities. Neither option completely satisfied all operational and usage requirements, either in terms of capabilities or costs. In the near term, UPS is using cellular systems to provide an initial nationwide mobile data communications capability. However, after much effort, UPS determined that the most cost effective long term alternative, and the only one giving it maximum control and operational flexibility, was to build our own mobile data radio system.

To meet UPS's requirements, II Morrow developed 220 MHz narrowband digital FM radios and system technology for mobile data communications. II Morrow's 220 MHz Vehicle Communications Network has demonstrated significant cost savings and performance improvements over previous methods and existing communications systems.

In 1991, UPS performed proof of concept field tests. In October 1992, it began conducting complete 220 MHz mobile data radio and system tests in Portland, Oregon. In February 1993, it received type acceptance for both its mobile data radios and base stations.

Testing and evaluation of II Morrow 220 MHz products and the UPS system continues. Most recently, UPS used 220 MHz communications for its On Call Air (OCA) vehicles in Portland. Results have been excellent, with significant operational advantages and cost savings demonstrated over the public access RF system which usually supports OCA.

This Appendix presents UPS's perspective on various technology options for refarming. UPS also provides examples of spectrum efficiency comparison for practical applications and mobile RF coverage conditions.

2. Technology Assessments

2.1. Single Channel Systems Technology Assessments for 5 kHz, 6.25 kHz, and 12.5 kHz Channel Spacing

2.1.1. Spectrum Efficiency

The following sections supply important background on spectrum efficiency. Section 3 contains quantified comparisons of spectrum efficiency of systems using various modulations and bandwidths.

2.1.1.1. 5 kHz Channels

Type accepted equipment for 5 kHz channels in the 220 MHz band includes: narrowband digital FM radios with nonlinear amplifiers; amplitude compandored single sideband (ACSSB) radios with linear amplifiers; and transparent tone in band (TTIB) linear radios. [1-6] Real zero single sideband (RZSSB) is another narrowband linear modulation with published measured performance. [7][1] With linear amplifiers, $\pi/4$ QPSK can be used in 5 kHz channels. [8] Other modulations have also been analyzed for narrowband use, such as differential amplitude phase shift keying (DAPSK).

Single sideband analog voice transmission in 5 kHz channels has been available for some time. Emerging techniques can support high quality digital voice in 5 kHz land mobile channels. However, channel separation narrower than 5 kHz makes high quality voice less practical, either by analog or digital means, unless adjacent channel coordination is used.

Channel spacing of 5 kHz provides up to six times as many voice channels per unit bandwidth as existing mobile radio systems. For many applications, communicating data can be conservatively estimated to yield a further order of magnitude improvement in information capacity per unit bandwidth, compared to analog or digital voice.

Practical, highly efficient multiple access data systems can operate in channels as narrow as 5 kHz. [9][2] Due to factors such as bandpass filter complexity, limitations of amplifier linearity, and Rayleigh fading, channels narrower than 5 kHz will tend to limit spectrum efficiency.

2.1.1.2. 6.25 and 12.5 kHz Channels

If data rates are scaled to channel separation, and other modulation parameters are similar, wider bandwidth systems may involve less adjacent channel interference (ACI) effects, but with somewhat worse sensitivity. Careful tailoring of modulation parameters can allow 6.25 kHz or 12.5 kHz system designers to trade off ACI performance to regain part of the lost sensitivity.

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[1] The numbers in brackets refer to the references listed at the end of this Appendix.

[2] Reference [9] is included in these Reply Comments as Appendix 2.

2.1.1.3. Effective Narrowband Masks Allow a Broad Range of Modulations and Full Adjacent Channel Use

Use of adjacent channels without distance separation requirements is critical in attaining full spectrum efficiency in PLMR bands. This is especially true if a flexible matrix of cochannel reuse distances is employed.

Emission masks in the NPRM are based on the 220 MHz mask. The 220 MHz rules were developed through the FCC's customary process of open public proposals and comments. Several commenters contributed detailed mask proposals. UPS's inputs were backed by extensive simulations and experiments with several RF technologies, including both linear and

2.1.1.4. 220 MHz Type Acceptance Reports Establish De Facto Standards for Narrowband Tests and Measurements

Three different narrowband technologies have been granted FCC type acceptance in the 220 MHz band, with lab reports on file with full details of test equipment and procedures. UPS particularly suggests reports from two of the type accepted technologies as models for emission test procedures for refarmed bands.

Type acceptance submittals by Stevens Engineering Associates provide examples of emission tests for linear radios with analog voice and a digital modulation mode.[4]

Type acceptance submittals by II Morrow include test methods for UPS' digital FM radios.[5] The UPS mobile type acceptance includes rigorous mask compliance with transmission bursts as short as 24 ms. [1,9]

Controlled burst signaling provides crucial advantages for reliable packet data throughput in Rayleigh faded land mobile channels. Burst spectrum control requires careful transmitter and system design, whatever the modulation. As packet data systems become more common, verifying mask compliance for burst operation will be increasingly important. [9]

2.1.1.5. Further Specifics on Emission Masks and Channel Reuse

The NPRM's proposed emission rules for 5 kHz and 6.25 kHz channels in refarmed bands include mask shapes and measurement bandwidths identical to or very similar to those set forth in Section 90.209(l) of the Rules now in effect for the 220 MHz band. Some other specific details are important for gaining the full benefit of 220 MHz research in the refarmed bands. Interference protection for spectrum efficiency also requires that emission rules for all refarmed bands include two other key provisions of 90.209(l), namely: attenuation of emissions up to 1.75 kHz (2.1 kHz for 420-512 MHz) outside the authorized bandwidth should be measured relative to the highest emission within a 100 Hz bandwidth within the authorized bandwidth; and emission power should be measured in peak values. Interference protection for spectrum efficiency also requires that footnote 12 of 90.205(b), use of peak envelope power (PEP) in determining effective radiated power (ERP), be applied to refarmed bands.

In cases of cochannel reuse with flexible mileage separations, whether by engineering in

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[4] See References 3 and 4.

[5] See References 1 and 2.

or by use of tables, use of 40/22 dBu cochannel reuse criteria, or similar criteria, such as 39/21 dBu, or 37/19 dBu, for all refarmed bands, will help optimize spectrum efficiency. The ratio can be expressed as a table of mileage separation and, in special circumstances, engineered in to meet unusual conditions. The UPS system design includes means of attaining reliable throughput in harsher interference, but these reuse criteria will provide for high performance with a variety of technologies. Several commenters provided other helpful input on ERP/HAAT, mileage separations, and other factors in reuse; UPS is confident that the FCC will be able to meld these comments into effective reuse rules.

2.1.2. Operational Features and Characteristics

2.1.2.1. 5 kHz Technology

The FCC has granted 220 MHz type acceptance for linearly amplified ACSSB and TTIB radios, and for nonlinearly amplified digital FM radios. The ACSSB and FM radios provide examples of US technology development encouraged by FCC spectrum efficiency initiatives. The type accepted TTIB radios are based on British research, matured into products by a US company.

The ACSSB radios are type accepted for analog voice transmission, or data transmission at 1,200 bits per second (1.2 kbps), with 20 W PEP. [3,4] The 220 MHz digital FM radios were developed by UPS' II Morrow subsidiary. They are type accepted for 4 kbps, with nonlinear amplifiers delivering a controllable .25 W to 50 W mobile output and up to 100 W base station output. [1,2]

As mentioned previously, the UPS mobile type acceptance also includes full spectrum control for rapid signal bursts as short as 24 ms in duration. FM detection methods provide crucial advantages in reliable reception of these controlled data bursts in Rayleigh faded land mobile channels. Rapid burst signaling is vital for efficient packet data systems. For many

Section 3 provides more detail on tradeoffs between bit rate, signaling efficiency, throughput, and coverage for 5 kHz technology options.

2.1.2.2. UPS 220 MHz Narrowband Digital FM Technology: a Tested Example of New Levels of Spectrum Efficiency

The UPS system includes many features which are just as significant as the RF bit rate in optimizing spectrum efficiency in the sense of reliable transfer of useful information per unit bandwidth per unit time. [9]

Narrowband digital FM, in concert with innovative multiple access, automatic repeat request (ARQ), forward error correction (FEC), and error detection enable the UPS system to reliably transfer thousands of messages per hour through each 5 kHz channel. Complete packet transfers can be completed in fractions of a second. Each channel can support hundreds of mobiles, using flexible combinations of random and directed access.

UPS publicly presented key performance results for its 220 MHz technology at the 1993 IEEE Vehicular Technology Conference (VTC). A paper describing UPS's 220 MHz system appears in the 1993 VTC Proceedings. The paper is attached as Appendix 2 to the UPS Reply Comments. Further development has continued since the paper went to press.

Recent II Morrow engineering progress includes bench and field tests of enhanced 4 kbps narrowband FM. The tests show that at the 10^{-2} bit error rate (BER) level, i.e. about 95% FEC block success, this enhanced modulation can attain an improvement of about three dB over the sensitivity and interference performance results reported in Appendix 2. This improvement can be attained without compromising the UPS system's capability for reliable use of rapid, controlled RF bursts. Quick burst FM signaling enables efficient error detection and ARQ methods to convert 95% block success into 100% correct messages with minimal time consumed in repeating portions of messages.

II Morrow lab tests have demonstrated good quality digital voice with reasonable speaker recognition, with a total 4 kbps transmission rate, including a 2.65 kbps voice codec and 1.35 kbps for FEC and trunking control.

For enhanced throughput in the UPS packet data system, II Morrow has also bench and field tested 6 kbps digital FM in recent weeks, with RF emissions within the 220 MHz mask. Reports in the literature show that with advanced voice codec and FEC methods, 6 kbps can support very high quality digital voice at BERs as high as 6×10^{-2}. [14] Ongoing II Morrow development includes still higher bit rates with constant envelope modulation in 5 kHz channels, and further work on digital voice.

2.1.2.3. Practical Example of Two Order of Magnitude Spectrum Efficiency Improvement

UPS hub yard shifter communications provide an example of the tremendous spectrum efficiency gains attainable with narrowband mobile packet data communications. A typical UPS hub processes tens of thousands of packages per day. Long haul vehicles move large volume package containers, such as semi trailers, between hubs. In the hub yard, an area of several acres up to a few hundred acres, rugged "shifter" vehicles move volume containers between hub access bays and temporary holding points.

A medium to large hub typically uses up to fifteen shifters, with a 25 kHz voice radio channel used to direct the vehicles. During peak sorting hours, shifter activity becomes very intensive, and channel blockage often causes lost time waiting for new assignments.

Aside from the channel blockage and delay issues, pilot projects showed that shifter drivers preferred to use simple text messages on mobile data terminals, rather than straining to hear mobile radio voice instructions in a bustling hub yard.

UPS is building a "super hub" in Chicago. Plans have been made to provide 220 MHz communications for scores of shifters at the super hub. With the 220 MHz system, shifter status updates require less than one fifth of a second of channel time, including all necessary channel control and automatic repeat request (ARQ) signaling, instead of several seconds of voice transmission. Quick random access bursts allow each shifter to send status updates as needed, without consuming air time with unnecessary polling. For intensive peak period operations, with dozens of packet transfers per hour for each vehicle, UPS 220 MHz technology can support up to 300 shifters with less than half the capacity of a 5 kHz channel.

Simple ratios of vehicles served, channel bandwidths, and percent channel usage show a two order of magnitude improvement in spectrum efficiency for this practical example. This is not an isolated case. UPS expects packet data systems to become increasingly widespread over the next several years for demanding business, industrial, and public safety applications, due to ease of use as well as spectrum efficiency. Part of the improvement comes from using data rather than voice. In addition, UPS's 220 MHz technology attains significant efficiency advantages over other existing and emerging mobile RF data systems.

2.1.2.4. Coverage Capability of UPS 220 MHz System

Published lab tested sensitivity of UPS radios is -117 dBm at a BER of 10^{-2}, which yields about 95% FEC block success. [9] As mentioned in section 2.1.2.2., at this block success level, the UPS system attains 100% correct messages with very little overhead. Section 2.1.2.2. also mentioned recent UPS tests showing further improvements in sensitivity can be attained.

The UPS system's channel access signaling, FEC, and ARQ work in concert to adapt data throughput to actual channel conditions. Efficient channel access and FEC provide very high throughput and low delay in heavy loading conditions. FEC and ARQ work together to for the base. In addition to intermodulation protection for receivers, UPS 220 MHz designs include measures to prevent undesired intermodulation products from being generated by its base station transmitters. Notch and bandpass filter configurations can be cost effectively adapted to the requirements of each base station site, to prevent unwanted signals from entering the transmitter and causing intermodulation.

For cochannel interference (CCI), bench tests show 95% FEC block success at a 12 dB carrier to interference ratio (C/I) in additive white Gaussian noise (AWGN) channel conditions. As in the ACI tests, modulated UPS radios were used as both the desired and CCI signals. Similarly, field tests have shown 95% block success at 12 dB C/I in line of sight conditions, at interstate highway speeds. [9]

As mentioned previously, recent lab results with enhanced 4 kbps narrowband FM indicate that about 3 dB further improvement is attainable in CCI and ACI performance, as well as sensitivity, without sacrificing the rapid burst detection properties important to system throughput.

For data operations, as C/I values decrease, the UPS system gradually reduces throughput, but maintains reliable communications. In future upgrades, low data rate operation, such as 1 kbps, can extend operations still further into harsh noise and interference conditions. [9] Digital voice techniques can also give excellent performance in very difficult conditions at bit rates which can be supported in channels as narrow as 5 kHz using UPS's digital FM technology.

Although well designed packet data systems can extend coverage into very harsh conditions, UPS recommends that cochannel reuse criteria such as 40/22 dBu, 39/21 dBu, or 37/19 dBu be applied to all refarmed bands. This will allow for quality performance and highly flexible cochannel reuse with a wide variety of technologies.

2.1.3. Costs

Narrowband FM digital radios require additional digital processing, and more selective IF filters than typical FM radios. Other than these factors, there is no inherent cost difference for narrowband FM radios vs. current land mobile equipment. Digital processing hardware costs continue to fall at a dramatic rate, even as capabilities continue to climb.

Compared with FM, linear radios such as ACSSB, TTIB, DAPSK, RZSSB, or $\pi/4$ QPSK pose some added complexity. Ongoing advances in amplifier linearization can mitigate but not totally eliminate this difference. RZSSB also relies on mobile antenna diversity in Rayleigh fading, which is an added cost factor. [7]

2.1.4. Availability

With straightforward analog design changes, technology which meets 220 MHz standards can be adapted to other bands. Using software control, radios such as UPS's can also adjust modulation parameters to optimize performance with dynamically variable data rates. Further development can lead to products with software controlled receiver IF filtering, as well.

2.2. TDMA Technology Assessments

2.2.1. Spectrum Efficiency

With rapid discriminator or differential detection of modulations such as narrowband digital FM, DAPSK, or $\pi/4$ QPSK, and precise burst spectrum control, mobile data systems can attain the advantages of TDMA, and other forms of multiple access, in channels as narrow as 5 kHz. [9,15] Narrowbanding does not preclude highly efficient digital multiple access, though TDMA digitized voice, which in many respects is considerably less spectrum efficient than data, can require more bandwidth.

2.2.2. Operational Features and Characteristics

As discussed in preceding paragraphs, efficient narrowband FM, DAPSK, or $\pi/4$ QPSK data systems can attain the advantages of TDMA, and other more efficient multiple access schemes, without the decreased flexibility inherent in wideband solutions. Due to the constant envelope property of FM radios, i.e. average power output equals PEP, FM provides further advantages in robust data performance in limited power or harsh interference conditions. Section 3.2.3. discusses this further.

2.2.3. Costs

Wideband TDMA systems may require somewhat more DSP at the base station than narrowband systems, but fewer base stations. Using narrowband multiple access systems offers greater flexibility in licensing and area coverage. A mixture of wideband and narrowband offers the best answer.

2.2.4. Availability

Efficient data equipment has already been type accepted for 220 MHz. These designs can be adapted to different bands and bandwidths.

2.3. Spread Spectrum Technology Assessments

2.3.1. Spectrum Efficiency

Spread spectrum is not a panacea for noise and interference issues. The usable data rates and voice codec bit rates for spread spectrum systems are orders of magnitude less than their RF bit rates. Whether frequency hopped or direct sequence, as the number of users and service area become large, spread spectrum is subject to ultimate throughput and coverage limitations, similar to other mobile radio schemes.

The NPRM proposes use of direct sequence spread spectrum for covert public safety operations. Even in this limited context, spread spectrum emissions must be stringently controlled.

To protect primary user from interference, maximum allowed spread spectrum PEP falling within the passband of any single channel width within the band of the spread spectrum emissions should be about -75 dBc relative to the allowed PEP for primary users, e.g. -75 dBc per 4 kHz with 5 kHz channel spacing.

2.3.2. Operational Features and Characteristics

General use of spread spectrum may offer some degree of improvement in security, but imposes a commonly shared infrastructure, and ongoing operational control of modulation, signaling, and transmit power, on all users of an entire band. This would negate the purpose of the PLMR Service, which exists to provide flexibility for varied users, not to mandate uniform use of very large blocks of spectrum.

2.3.3. Costs

Spread spectrum entails moderate added cost for individual radios. Infrastructure costs for general use of wide area spread spectrum systems are likely to be very large. Depending on implementation details, useful dynamic range within a given cell may be limited. This generally equates to limited coverage area per base station, raising system costs for suburban and rural areas. Similarly, depending on system details, use for covert public safety operations may require considerably more base stations.

2.3.4. Availability

Unlike PLMR, the cellular service is characterized by very large blocks of spectrum placed under regional authority of individual licensees or controlling entities. Consequently, there has been considerable discussion of spread spectrum techniques in the arena of proposed digital cellular systems.

2.4. Wideband Data Technology Assessments

2.4.1. Spectrum Efficiency

With advanced digital technology, spectrum efficiency is not really a question of narrowband vs. wideband channels. The real challenge is to use both options in flexible combinations, to meet particular communications needs.

Metropolitan, regional, or nationwide contiguous channel blocks, with various modulations and bandwidths allowed within the block, would allow licensees to use both wide and narrow channels within the same block, and to employ highly creative reuse schemes.

The next key is system technology for efficiently adaptable data rates within given cells, and variation of data rates and bandwidths from cell to cell. With these tools in hand, a contiguous block licensee could employ either narrowband cellular reuse or widebanding in dense use areas, depending on whether it was more important to increase capacity or reduce infrastructure cost. Narrowbanding would provide reliable throughput in zones of heavy interference, and reduced infrastructure cost in rural settings where area coverage poses a greater challenge than capacity.

2.4.2. Operational Features and Characteristics

The optimum scenario for cost effective spectrum efficiency in refarmed bands includes the use of contiguous channel blocks, with the licensee employing both wideband and narrowband modulation.

A contiguous block equivalent to ten narrowband channels, and certainly no more than fifteen or twenty, could provide the basis of a cost effective, very large scale system. A five channel block would provide an adequate basis for a medium to large scale system.

2.4.3. Costs

Radios for the optimal contiguous block scheme need not cost much more than efficient narrowband digital radios. Combined use of narrowband and wideband modulation can decrease the required number of base stations, reducing infrastructure costs.

2.4.4. Availability

Technology to support a mixed bandwidth contiguous block scheme can be made readily available by straightforward modifications to 220 MHz digital equipment designs. The UPS 220 MHz system already includes microprocessor controlled modulation, efficient multiple access, channel coding, wide area networking, synthesized mobile frequency flexibility, and power control. The system design allows for other features of a powerful contiguous block scheme to be added in the future. Remarks of some of the other participants in the May 6 FCC Roundtable indicated that they have considered similar concepts for multimode operations with linear modulations. [16]

2.5. Mixed Voice-Data Systems Technology Assessments

2.5.1. Spectrum Efficiency

Linear modulations such as ACSSB, TTIB, and RZSSB can provide analog voice transmission in channels as narrow as 5 kHz. The first 220 MHz type acceptance included both analog voice and 1.2 kbps digital transmission. [3,4] TTIB and RZSSB have been tested at higher bit rates. [13,7]

As mentioned in section 2.1.2.2., ongoing UPS development shows that narrowband digital FM has the basic capability to support digital voice in narrowband channels. $\pi/4$ QPSK and DAPSK can also provide bit rates within the 220 MHz mask capable of supporting digital voice in 5 kHz channels. [17,18,14] With discriminator or differential detection, digital FM, DAPSK, and $\pi/4$ QPSK hold advantages in supporting efficient mobile packet data operations. [9,18,15]

For many applications, voice is a far less spectrum efficient means of conveying information than data. For many users, it is easier and more convenient, as well as much more spectrum efficient, to use text messages rather than voice. Two way text messaging using UPS's 220 MHz system has been field tested in actual package delivery and pickup operations, with very enthusiastic user response.

However, there are many situations where voice will probably never be replaced. Mixed voice-data operations have an important place in the future of PLMR.

2.5.2. Operational Features and Characteristics

The concept of using QPSK to attain 9.6 kbps in a channel which is nominally 6.25 kHz wide has roots in a digital cellular scheme for 48 kbps transmission in 30 kHz channels. [20] The digital cellular proposal assumes rigorous adjacent channel coordination, with at most every third channel used within a given cell, and was not designed for a PLMR environment.

The APCO 25 9.6 kbps Interim Standard is based mainly on a digital voice scheme which uses 7.2 kbps for a voice codec plus error correction bits. Due to the complications of simultaneous circuit switched digital voice signaling and packet switched data signaling, only a very low useful data rate, 89 bits per second, is available during voice transmissions.

As discussed in section 2.1.2.2., high quality digital voice with error correction and embedded signaling can be supported with RF bit rates as low as 6 kbps. Section 2.1.2.2. goes on to mention II Morrow experiments and analysis which indicate that 6 kbps, and even higher RF bit rates, can be practically attained with cost effective nonlinear radios in 5 kHz channels. If still higher data rates are deemed absolutely necessary, they can be attained in 5 kHz channels with modulations complying with an emission mask which allows uncompromised use of all adjacent channels.

APCO 25 proposes a "busy bit" CSMA protocol for data transmission in between voice transmissions. [19] As discussed in section 3.5., CSMA is not the most efficient option for mobile data protocols. Efficiently dovetailed modulation and signaling methods, such as the UPS system provides, can support much higher practical data throughput.

In summary, the operational features proposed for wider bandwidth voice-data systems can be attained in channels as narrow as 5 kHz, within an emission mask which allows full use of adjacent channels without coordination.

2.5.3. Costs

The discussion of section 2.1.4. applies here as well.

For the foreseeable future, many users will probably continue to prefer analog or digital voice communications over options such as data or text messages. However, since voice is in many ways much less spectrum efficient than data, voice-data systems will tend to require more base stations and channels than data-only systems, leading to increased infrastructure costs.

2.5.4. Availability

As mentioned in 2.1.4., RF technology which meets 220 MHz standards can be adapted to other bands. Digital FM, as well as various linear modulations, can provide the basis for high performance voice-data operations in channels as narrow as 5 kHz.

2.6. Tabulation of Technology Option Tradeoffs

Table 1 summarizes UPS's perspective on relative merits of refarming technical options.

Technology Assessments
Figures of Merit

	Spectrum Efficiency	Ease of Transition	Operational Features and Characteristics	Costs	Availability
Single Channel Systems with 5, 6.25, 12.5 Khz Channel Spacing	2	1	2	2	1
TDMA (Narrowband and Wideband Mix)	2	2	2	2	1
Spread Spectrum	3	3	3	3	3
Wideband Data (Flexible Blocks, Narrowband and Wideband Mix)	1	2	1	1	2
Mixed Voice-Data Systems	3	1	2	3	2

<u>Figures of Merit</u>:

1 = Most Favorable/Desirable Characteristics

3 = Least Favorable/Desirable Characteristics

3. Spectrum Efficiency Analysis Examples

Comparisons between different systems or technologies are not always simple. However, valid first order comparisons for particular applications or general classes of applications are possible.

If procedures for license awards based on spectrum efficiency are to be adopted, the examples shown here can serve as guidelines in developing legitimate criteria for weighing the relative merits of different technologies.

Discussions under way in Congress may mandate other criteria for mobile radio license awards. Regardless of the outcome of pending legislation, or its ultimate interpretation, UPS feels it is very important to provide quantified examples of tradeoffs between various mobile radio technical options, in order to contribute to the attainment of the FCC's laudable goals in Docket 92-235. The comments in Docket 92-235 contained many qualitative statements as to the relative merits of various technologies and bandwidths. The comparisons shown in the following sections indicate the engineering basis for UPS's approach to spectrum efficient mobile radio communications.

3.1. Defining Spectrum Efficiency

3.1.1. Common Measures of Spectrum Efficiency

For voice communications, spectrum efficiency can be stated simply in terms of channels per Hz. In digital terms, bits per second per Hz is a commonly used figure of merit for spectrum efficiency. These definitions could be made somewhat more complete for dense use areas by dividing by unit area, i.e. channels per Hz per square mile, or bits per second per Hz per square mile.

In rural areas where wide area coverage with reduced infrastructure cost is the system design goal, one might more appropriately multiply by area, instead of dividing. This would give figures of merit with dimensions of channels times square miles per Hz, or bits times square miles per second per Hz.